SearchLight – A Lightweight Search Function for Pervasive Environments

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Abstract. We present a lightweight search function for physical objects in instrumented environments. Objects are tagged with optical markers which are scanned by a steerable camera and projector unit on the ceiling. The same projector can then highlight the objects when given the corresponding marker ID. The process is very robust regarding calibration, and no 3D model of the environment is needed. We discuss the scenario of finding books in a library or office environment and several extensions currently under development.

1 Introduction

Ubiquitous computing landscapes extend our physical surroundings by a computational layer providing new functionalities. One such functionality can be the capability of objects to make themselves known in order to be noticed or found by humans. This functionality was already proposed in the original Ubiquitous Computing vision [8]. A search function for physical environments would alleviate the need to keep track of all of the things in our environment.

One obvious application is keeping track of books in our office, in a library or a book store. Let's think of a library with ubiquitous display capabilities. Let's assume there will still be a conventional inquiry terminal to find out about books. The inquiry interface on the computer terminal in a library could then just provide an additional "show this book" button for the selected book, which prompts the environment to highlight its position on the shelf.

Let's think of an instrumented office in which there are many books and other things, either neatly sitting on the shelf where they belong, or left somewhere in the room on a pile. A physical search functionality will find and highlight missing objects for us, no matter where we left them. In this paper we describe such a search function for physical objects, and how it was implemented in our instrumented environment.

2 The SUPIE environment

The Saarland University Pervasive Instrumented Environment (SUPIE) is an instrumented room with various types of displays, sensors, cameras, and other

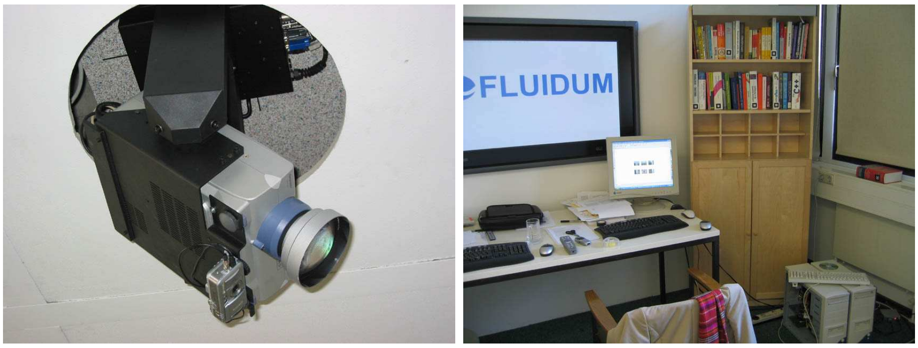

Fig. 1. The steerable projector mounted on the ceiling (left) and one corner of SUPIE with a book shelf (right)

devices. By means of a steerable projector, the room has continuous display capabilities which are limited in resolution and temporal availability (only one area at a time). The various other displays provide islands of higher resolution and interactivity within this display continuum.

Fig. 2. Images taken during the scanning process (left) and an example of an AR Toolkit marker (right)

The projector can project arbitrary light patterns onto all surfaces in the room with line of sight to its position in the center of the ceiling. An attached camera can take high resolution pictures from (almost) the same position and scan them for objects and markers. It also provides a low resolution video stream in real time for the recognition of movements.

3 Implementation of *SearchLight*

3.1 General Thoughts

All that is needed to implement *SearchLight* is the steerable projector with its camera and the capability to recognize optical markers. The only determining factors for finding objects and highlighting them, are the pan and tilt angles of the unit moving the projector. If a marker is found at given pan and tilt angles, these can be stored and used directly for projecting a highlight area around the corresponding object. Thus, not even a 3D model of the room is needed. Absolute registration errors of the camera and projector will cancel each other out since they are mounted in one unit and moved together.

3.2 Devices

The steerable projector is mounted on a moving yoke produced by a stage equipment manufacturer, controlled via a DMX interface, and mounted in the center of the ceiling of the room. The unit carries a 3.000 ANSI lumen projector with a lens of long focal length, in order to provide sufficient contrast and brightness in daylight. The camera attached to the projector (see figure 1 right) is a regular Digicam with an image resolution of four Megapixels. The high resolution pictures are triggered and read out over USB with the camera's freely available SDK. Each object that should be found by *SearchLight* is tagged by an AR Toolkit marker (see [1]). Each marker has a large black fringe and an individual small black symbol on a white background. (See figure 2) These markers are recognized by the Java version of AR Toolkit, the *JAR Toolkit*.

3.3 Implementation

SearchLight performs two main tasks: It *scans* the room for markers and memorizes the corresponding angles, which are used later to *show* searched objects.

Scan The room is scanned by taking slightly overlapping pictures in all horizontal and vertical directions (see Fig. 2 left). Each picture is analyzed using JAR Toolkit. Marker IDs are stored in a list together with their pan and tilt angle, derived from their position and orientation in the picture and the orientation of the moving yoke when taking the picture.

Show After the room has been scanned, the user can search for marked objects. The request to show a specific book in a library can, for example, be given from the library enquiry system through a "show this book" button. The object's Marker ID is then looked up and the projector unit moves to the position where this marker was detected during the last scan and projects a bright spot around the searched object. Due to the speed of the steerable projector, highlighting an arbitrary object takes less than a second, thus providing almost instant feedback to the search request.

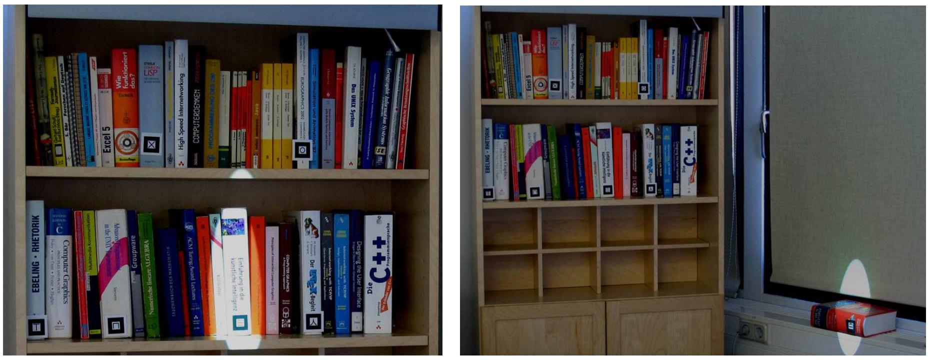

Fig. 3. A book was found on the shelf (left) and another one on the window sill (right)

4 Related Work

The use of a steerable projector to transform environments into continuous displays has first been proposed by Claudio Pinhanez [3] at IBM. In their Siggraph 2001 emerging technologies demo, where colored M&Ms were composed by visitors to form large pixel images, the Everywhere Display Projector was used to highlight trays with different colors on a shelf. The positions of these trays were, however, not acquired automatically.

Additional applications are presented in [4], including a ubiquitous product finder and an interactive shelf. The product finder guides people towards products in a store environment, using blank projection surfaces as individual direction signs and interaction spaces. The interactive shelf uses similar surfaces for the display of product-related information. While these prototypes are strongly related to the work presented here, both of them require dedicated projection space in the environment.

Raskar et al. present in [5] a method for simultaneous acquisition of room geometry and use of the acquired surfaces as an output medium for mobile projectors. They also use markers for object recognition and annotation. The FindIT Flashlight [2] can find objects instrumented with responsive elctronic tags. Users scan the environment with an electronic flashlight emitting a digital code, and the corresponding tags respond when hit by the flashlight's beam. Both systems rely on the user pointing to the right direction, while in our demo, the environment actively controls the projector.

In [7] another augmented library environment is described, where books or their requested positions can be highlighted on the shelf through a head-mounted display. While this approach is more general in terms of scalability and topology of the environment, it requires an instrumentation of the user and an explicit 3D model of the environment, which we were able to avoid.

5 Current Results and Future Work

One immediate application scenario is a public library where each book has a marker on its front and back side and on the spine. In this way a book can be located even if it is not at its usual place in the shelf. When the library is closed, *Search Light* can scan all shelves and tables and take inventory. During opening hours, only certain areas must be re-scanned as described above. With our experimental setup in SUPIE (room size 5x6m, shelf on the wall, 4 Megapixel steerable camera with 3x optical zoom in the center of the ceiling) we were able to reliably recognize markers down to a size of 10mm in the whole room. Initial scanning of the room took roughly 1 hour, mostly due to the slow transmission of pictures over the USB 1.1 link to the camera. Currently we are improving *SearchLight* in various respects.

5.1 Continuous Model Update

In the current demo, scanning is done only once when *SearchLight* is started. In the future we will use idle times of the projector to systematically re-scan the room for changes. This process will also prioritize regions where changes are more likely by using additional sensors, such as RFID tags or motion detection with other cameras. On the down side, including external sensors will require the use of at least a simple 3D model of the room in order to relate locations of sensor events to pan and tilt angles of the projector. This model might, however, be acquired automatically by methods similar to those described in [6]. Upcoming versions of *SearchLight* may use the camera even when the projector is used for other tasks by just analyzing images as they appear rather than actively steering the camera to certain positions for scanning.

5.2 Extension to Other Markers

In theory, existing bar codes on many products could be used for the recognition process. In the case of books, OCR could even eliminate the need for markers altogether, since book spines and covers are designed to clearly identify books. Currently, we are working on integrating RFID tags by watching the region around the RFID antenna. When the antenna registers a change in its field, a new image is taken and the exact position of the new resp. removed object is identified from a difference image. As a side effect the exact silhouette of the object might be obtained for highlighting by the projector. To overcome the visibility problems inherent to the use of optical markers, radio tags might even fully replace them. This will, on the other hand, make a 3D model of the environment necessary, in order to relate object positions to pan and tilt angles of the projector.

5.3 Fuzzy Search Results

If the exact position or dimension of a searched object is unknown, a fuzzy search result can be visualized as a spot whose diameter reflects the amount of uncertainty. If, in addition, we know the probabilistic distribution over possible locations, we can adjust the brightness of the spot to reflect this distribution. In the extreme case this means highlighting a whole area of the room, which would signify that the object must be "somewhere in that area".

6 Conclusions

We have discussed an approach to implementing a search functionality for physical environments by a steerable camera-projector unit, and we have shown that it is possible to implement this functionality without an explicit 3D model of the environment. One big advantage of our approach is, that no calibration between the projector-camera-unit and the environment is needed. One obvious limitation is that only objects within sight from the unit can be searched and found. This limits the topology of the environments in which our approach can be used.

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